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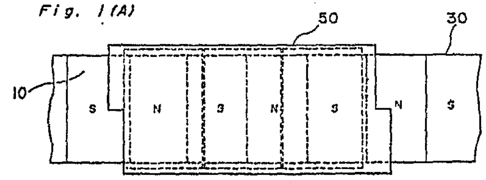
(54) **Linear motor and linear driving device employing said linear motor.**

(57) The disclosure is directed to a linear motor capable of sufficiently reducing cogging which may present obstruction in effecting constant speed control or positioning control at high accuracy, and also to a linear driving device utilizing the linear motor of the above described type.

Fig. 1(A)



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Description

Linear Motor and Linear Driving Device Employing Said Linear Motor

BACKGROUND OF THE INVENTION

The present invention generally relates to an electric motor, and more particularly, to a linear motor most suitable for a positioning control, speed control or the like at high accuracy and also, to a linear driving system employing such linear motor.

Conventionally, a linear motor includes a field magnet in which N and S magnetic poles of permanent magnets are alternately arranged, and an armature coil, and is so arranged as to relatively displace the armature coil or the field magnets by successively changing over the current to be supplied to said armature coil. The linear motor as described above may be classified into a coreless type having only an air-core armature coil, and into a cored type having windings wound onto projecting poles. In the above two types, the coreless type linear motor requires a large-sized stator yoke in order to obtain the field over an entire length of the linear motor, while the other cored type linear motor requires an armature core to form projecting poles for winding the armature coil, thus both types presenting serious problems for achieving compact size and weight reduction of the linear motors.

In order to overcome the disadvantages as described above, there has also conventionally been proposed a linear motor as shown in Fig. 8, which includes a movable member 6 having a magnetic pole iron plate 5 and polyphase windings 4, and a stator field member 3 having field magnets 1 and a yoke 2 so as to freely move the movable member 6 with respect to the field magnets 1 through polyphase excitation of the polyphase windings 4. It is to be noted here that, in the above known arrangement, as a method of reducing cogging to be produced in the movable member 6, it is so arranged as to alleviate the magnetic reluctance variation based on the displacement of the movable member as a main cause for generation of cogging by devising shapes at the forward ends of the iron plate 5 in the similar manner as in the iron-core type linear motor, thereby to lower cogging generating level.

In the above known arrangement, however, the present state is such that, as a result, cogging can not be fully reduced to a permissible level, since the magnetic pole iron plate 5 has the complicated shape at its forward end portions, with high accuracy being required for processing thereof. In other words, cogging becomes a serious cause of disturbance for effecting a constant speed control at high accuracy, while also presenting a large obstruction in the case where positioning control at high accuracy is to be effected.

SUMMARY OF THE INVENTION

Accordingly, in one aspect the present invention aims to provide a linear motor capable of sufficiently reducing cogging which may present obstruction in effecting the constant speed control or positioning control at high accuracy.

In another aspect the present invention aims to provide a linear driving device employing the linear motor of the above described type.

In accomplishing these and other aims, according to one aspect of the present invention, there is provided a linear motor which includes a stator field member having many permanent magnets and a yoke, and a movable member having polyphase windings and a magnetic pole iron plate and disposed to confront said stator field member in a plane, thereby to relatively displace said movable member with respect to said stator field member through polyphase exciting of said polyphase windings. Said magnetic pole iron plate has a geometrical shape obtained by dividing said magnetic pole iron plate into two rectangular regions of equal size and configuration with respect to a geometrical center axis in a displacing direction of said linear motor and displacing said rectangular regions in a parallel relation in the forward and backward directions of displacement of the linear motor.

In another aspect of the present invention, there is also provided a linear driving device utilizing linear motors, which comprises a set of two linear motors each including a stator field member having many permanent magnets and a yoke, and a movable member having polyphase windings and a magnetic pole iron plate and disposed to confront said stator field member in a plane, thereby to relatively displace said movable member with respect to said stator field member through polyphase exciting of said polyphase windings, and a structure member having a rigidity and connecting to each other, the two movable members in the two liner-motors disposed in the direction of displacement. The two movable members are disposed in a parallel relation to each other, and relative positions of the magnetic poles in said two stator field members corresponding to said two movable members are arranged to be deviated from each other, or to be identical with each other, with relative positions of the two pole iron plates in said two movable members being adapted to be deviated from each other.

In the linear motor for the one aspect, since the phases of the cogging forces acting respectively on the two rectangular regions divided in the magnetic pole iron plate are to be deviated according to the relative positions with respect to the stator field in the two rectangular regions, such cogging forces for the both regions are offset each other.

Meanwhile, with respect to the linear driving device employing the linear motor according to the another aspect, the phases of the cogging forces respectively acting on the two movable members connected to each other by the structure member and disposed in the parallel relation, are to be deviated according to the relative positions of the magnetic poles in the two stator field members, and therefore, such cogging forces for the both are also offset each other. Similar result may be obtained in

the case where the relative positions of the magnetic pole iron plates in the two movable members are deviated from each other, with the relative positions of the magnetic poles in the two stator field members being set to be identical.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

Fig. 1(A) is a fragmentary top plan view of a linear motor according to a first embodiment of the present invention,

Fig. 1(B) is a schematic side elevational view of the linear motor of Fig. 1(A),

Fig. 2(A) is a top plan view showing a geometrical configuration of a rectangular type magnetic pole iron plate, in the case where the length L thereof is (n+1/2) times the magnetic pole pitch p,

Fig. 2(B) is a view similar to Fig. 2(A), which particularly shows a geometrical configuration of an indented type magnetic pole iron plate, in the case where the length L thereof is (n+1/2) times the magnetic pole pitch p,

Fig. 3(A) is a top plan view showing a geometrical configuration of a rectangular type magnetic pole iron plate, in the case where the length L thereof is (n) times the magnetic pole pitch p,

Fig. 3(B) is a view similar to Fig. 3(A), which particularly shows a geometrical configuration of an indented type magnetic pole iron plate, in the case where the length L thereof is (n) times the magnetic pole pitch p,

Figs. 4(A) and 4(B) are graphs showing relation between displacing amounts of the rectangular type magnetic pole iron plate and cogging forces acting thereon when said iron plate is displaced from a reference position,

Fig. 4(C) is a graph showing relation between a length L of the magnetic pole iron plate and a peak value of cogging force,

Fig. 5 is a schematic top plan view showing a general construction of a linear driving device employing the linear motors according to the present invention,

Fig. 6 is a graph showing relation between the displacing amounts of the movable members from a reference position and the cogging forces acting on the respective movable members,

Fig. 7 is a view similar to Fig. 4, which particularly shows a modification thereof, and

Fig. 8 is a fragmentary side elevational view showing construction of a conventional linear motor (already referred to).

DETAILED DESCRIPTION OF THE INVENTION

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Referring now to the drawings, there is shown in Figs. 1(A) and 1(B), an improved linear motor 70 according to one preferred embodiment of the present invention, which generally includes a stator field member 30, and a movable member 60 movably provided above the stator field member 30 through a restricted interval therebetween for displacement in the longitudinal direction of said stator field member 30.

The stator field member 30 referred to above is constituted by a plurality of permanent magnets 10 alternately magnetized with N and S poles and a yoke 20, while the movable member 60 further includes polyphase windings 40 provided with a plurality of armature coils and a magnetic pole iron plate 50 supporting said polyphase windings. In other words, the linear motor 70 constituted by the movable member 60 and the stator field member 30 as described above is arranged to displace the movable member 60 with respect to the stator field member 30 by successively exciting the polyphase windings 40.

More specifically, the magnetic pole iron plate 50 employed in the above embodiment has an indented shape as shown in Fig. 2(B). On the assumption that a magnetic pole iron pate having a length L and a width W as shown in Fig. 2(A) is divided into a rectangular region I (a rectangle AOO'D) and a rectangular region II (a rectangle OBCO') of the equal size and shape with respect to a geometrical central axis OO' thereof (i.e. a central axis for dividing the magnetic pole iron plate into two portions in a direction of the width), the magnetic pole iron plate 50 in the first embodiment has a geometrical shape in which the rectangular regions I and II are parallelly displaced from each other. In short, the magnetic pole iron plate 50 is divided into the rectangular region I (rectangle AEGD) and the rectangular region II (rectangle FBCH) which are parallelly displaced from each other so as to be in the indented shape on the whole as shown in Fig. 2(B). The length L and the parallel displacing amount are set in the manner as represented by following equations

$L = [n + (1/2)]p$

$EF = GH = (p/4)$

where n is a natural number and p is a magnetic pole pitch for the permanent magnets 10.

Subsequently, the principle for reducing cogging by the linear motor having the construction as described so far will be described with reference to a graph of Fig. 4(A) showing relation between the displacing amount and cogging force acting on the magnetic pole iron plate in the case where the rectangular magnetic pole iron plate is displaced from a reference position, and also to a graph of Fig. 4(C) denoting relation between the length L of the magnetic pole iron plate and peak value of the cogging force.

Cogging takes place in association with a large variation of magnetic reluctance in the vicinity of alternate magnetic pole boundary of the stator field member 30 when the magnetic pole iron plate 50 passes therethrough, and in the case where the magnetic pole iron plate has a geometrical configu-

ration in the rectangular shape, the cogging force approximated by a sine wave with an amplitude A and cycle T is acting as shown in Fig. 4(A). Such amplitude A and cycle T may be determined by a magnetomotive force U of the permanent magnets 10, the length L and width W of the magnetic pole iron plate, and the magnetic pole pitch p, and the level of the cogging force becomes minimum when the length L of the magnetic pole iron plate is represented by $[n+(1/2)]p$ as shown in Fig. 4(C). It is to be noted here that, in the cogging forces acting on the rectangular magnetic pole iron plate, those respectively acting on the rectangular regions I and II as shown in Fig. 2(A), are of the same phase and waveform.

Meanwhile, although the cogging force acting on the indented magnetic pole iron plate 50 is produced as a result of combination of the cogging forces acting respectively on the rectangular regions I and II as shown in Fig. 2(B), since the relative position of the rectangular regions I and II with respect to the stator field member 30 is deviated by p/4 in this case, the cogging forces acting on the both are to be offset each other, with a difference only in phase, and consequently, the level of the cogging is to be lowered. Furthermore, in the case where the length L of the magnetic pole iron plate 50 is represented by $[n+(1/2)]p$, and the parallel displacing amount for the rectangular regions I and II is denoted by p/4, both of the cogging forces are to be offset each other, and thus, optimum result may be achieved.

Referring further to Figs. 3(A) and 3(B), a modification of the linear motor and the linear driving device employing the linear motor according to the present invention will be described hereinbelow.

The construction of the linear motor 70 to which the magnetic pole iron plate according to the modification of the present invention may be applied is generally the same as that described with reference to Figs. 1(A) and 1(B), and therefore, detailed description thereof is abbreviated here for brevity.

The modified magnetic pole iron plate 50, employed in the linear motor of the present invention has an indented shape as shown in Fig. 3(B). On the assumption that a magnetic pole iron pate having a length L and a width W as shown in Fig. 3(A) is divided into a rectangular region I (a rectangle AOO'D) and a rectangular region II (a rectangle OBCO') of the equal size and shape with respect to a geometrical central axis 00' thereof (i.e. a central axis for dividing the magnetic pole iron plate into two portions in a direction of the width), the magnetic pole iron plate 50' of the modification has a geometrical shape in which the rectangular regions I and II are parallelly displaced from each other. In short, the magnetic pole iron plate 50 is divided into the rectangular region I (rectangle AEGD) and the rectangular region II (rectangle FBCH) which are parallelly displaced from each other so as to be in the indented shape on the whole as shown in Fig. 3(B). The length L and the parallel displacing amount are set in the manner as represented by following equations

$L = np$

$EF = GH = (p/4)$

where n is a natural number and p is a magnetic pole pitch for the permanent magnets 10.

Subsequently, the principle for reducing cogging by the linear motor having the construction as described so far will be described with reference to a graph of Fig. 4(B) showing relation between the displacing amount and cogging force acting on the magnetic pole iron plate in the case where the rectangular magnetic pole iron plate is displaced from a reference position.

Cogging takes place in association with a large variation of magnetic reluctance in the vicinity of alternate magnetic pole boundary of the stator field member 30 when the magnetic pole iron plate 50' passes therethrough, and in the case where the magnetic pole iron plate has a geometrical configuration in the rectangular shape, the cogging force approximated by a sine wave with an amplitude A and cycle T is acting as shown in Fig. 4(B). It is to be noted here that, in the cogging forces acting on the rectangular magnetic pole iron plate, those respectively acting on the rectangular regions I and II as shown in Fig. 3(A), are of the same phase and waveform.

Meanwhile, although the cogging force acting on the indented magnetic pole iron plate 50' is produced as a result of combination of the cogging forces acting respectively on the rectangular regions I and II as shown in Fig. 3(B), since the relative position of the rectangular regions I and II with respect to the stator field member 30 is deviated by p/4 in this case, the cogging forces acting on the both are to be offset each other, with a difference only in phase, and consequently, the level of the cogging is to be lowered.

Referring further to Figs. 5 and 6, a linear driving device employing the linear motor according to the present invention will be described hereinafter.

In Fig. 5, the linear driving device 80A generally includes two linear motors 71 and 72 disposed in a parallel relation to each other, and movable members 61 and 62 connected to each other by a structure member 90 having a rigidity and adapted to be freely displaced. The linear motor 71 is fundamentally constructed by a stator field member 31 having permanent magnets 11 alternately magnetized by N and S poles and a yoke (not shown), and the movable member 61 having a rectangular magnetic pole iron plate 51 and polyphase windings (not shown). Although the other linear motor 72 is similarly constituted by a stator field member 32 having permanent magnets 12 alternately magnetized by N and S poles and a yoke (not shown) and the movable member 62, the relative positions between the permanent magnets 11 and 12 are deviated by p/2. It is to be noted that the magnetic pole iron plates 51 and 52 for the linear motors 71 and 72 are equal to the magnetic pole iron plate as shown in Fig. 3(A).

Referring also to Fig. 6, principle for reducing cogging in the linear driving device having the construction as described so far will be explained hereinafter.

In short, owing to the construction that the relative

positions of the permanent magnets 11 and 12 are deviated by p/2, the cogging forces respectively acting on the movable members 61 and 62 will be in opposite phases. Moreover, since the movable members 61 and 62 are connected to each other by the structure member 90, the cogging forces acting on the both are to be cancelled, and consequently, the cogging produced on the movable members 61 and 62 are remarkably reduced.

It should be noted here that the arrangement in the foregoing embodiment in which the relative positions of the permanent magnets 11 and 12 are deviated by p/2 may be so modified as in a modification of Fig. 7 in which the relative positions of the movable members 61 and 62 are deviated by p/2 so as to obtain a similar effect.

Accordingly, by the linear motor and the linear driving device employing said linear motor of the present invention as described so far, generation of cogging may be advantageously reduced through a simple method for practical applications, and therefore, the present invention is particularly significant in that disturbance in control systems can be markedly reduced in the case where a constant speed control or positioning control is to be effected at higher accuracy, with an attempt for small size and light weight.

It should also be noted here that the linear motor and the linear driving device of the present invention are not limited to the foregoing embodiments, but may further be modified in various ways within the scope, for example, in such a manner that, by connecting both movable members including indented type magnetic pole iron plates through a structure member, the relative positions of these movable members and the permanent magnets in the stator field members are deviated.

As is clear from the foregoing description, according to the linear motor and the linear driving device utilizing said linear motor of the present invention, since the system in which the cogging forces acting on the movable members are cancelled on the whole is employed, instead of the system for alleviating the magnetic reluctance variation based on the displacement of the movable members which is the main cause of cogging generation, and moreover, said system may be effected comparatively easily through alteration of the configuration of the magnetic pole iron plate or variation of relative position between the permanent magnets in the fixed stator field members and the movable members, cogging may be sufficiently reduced down to a permissible level consequently. Therefore, it becomes possible to realize a very superior servo-motor for effecting positioning control or speed control at high accuracy.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.

There are described above novel features which the skilled man will appreciate give rise to advantages. These are each independent aspects of the invention to be covered by the present application, irrespective of whether or not they are included within the scope of the following claims.

Claims

1. A linear motor which comprises a stator field member (30) having many permanent magnets (10) and a yoke (20), and a movable member (60) having polyphase windings (40) and a magnetic pole iron plate (50) and disposed to confront said stator field member (30) in a plane, thereby to relatively displace said movable member (60) with respect to said stator field member (30) through polyphase exciting of said polyphase windings (40), said magnetic pole iron plate (50) having a geometrical shape obtained by dividing said magnetic pole iron plate (50) into two rectangular regions of equal size and configuration with respect to a geometrical center axis (O-O′) in a displacing direction of said linear motor (70) and displacing said rectangular regions in a parallel relation in the forward and backward directions of displacement of said linear motor.

2. A linear motor as claimed in Claim 1, wherein the parallel displacing amount of the rectangular regions in the magnetic pole iron plate (50) having a length of $[n+(1/2)]p$ is represented by p/4, where n is a natural number, and p is a pole pitch of said stator field member (30).

3. A linear motor as claimed in Claim 1, wherein the parallel displacing amount of the rectangular regions in the magnetic pole iron plate (50) having a length of np is represented by p/4, where n is a natural number, and p is a pole pitch of said stator field member (30).

4. A linear driving device utilizing linear motors, which comprises a set of two linear motors (71,72) each including a stator field member (31, 32) having many permanent magnets (11, 12) and a yoke, and a movable member (61, 62) having polyphase windings and magnetic pole iron plate (51, 52) and disposed to confront said stator field member (31, 32) in a plane, thereby to relatively displace said movable member (61, 62) with respect to said stator field member (31, 32) through polyphase exciting of said polyphase windings, and a structure member (90) having a rigidity and connecting to each other, the two movable members (61, 62) in the two linear motors (71, 72) disposed in the direction of displacement, said two movable members (61, 62) being disposed in a parallel relation to each other, with relative positions of the magnetic poles in said two stator field members (31, 32) corresponding to said two movable members (61, 62) being arranged to be deviated from each other.

5. A linear driving device utilizing linear

motors, which comprises a set of two linear motors (71, 72) each including a stator field member (31, 32) having many permanent magnets (11, 12) and a yoke, and a movable member (61, 62) having polyphase windings and a magnetic pole iron plate (51, 52) and disposed to confront said stator field member (31, 32) in a plane, thereby to relatively displace said movable member (61, 62) with respect to said stator field member (31, 32) through polyphase exciting of said polyphase windings, and a structure member (90) having a rigidity and connecting to each other, the two movable members (61, 62) in the two linear motors (71, 72) disposed in the direction of displacement, said two movable members (61, 62) being disposed in a parallel relation to each other, with relative positions of the magnetic poles in said two stator field members (31, 32) corresponding to said two movable members (61, 62) being arranged to be identical, and with relative positions of the two magnetic pole iron plates (51, 52) in said two movable members (61, 62) being adapted to be deviated from each other.

6. A linear motor comprising a stator field member having a linear array of magnetic field generating elements and a movable member including polyphase windings and a ferromagnetic pole plate, said movable member being linearly movable along said array by excitation of said polyphase windings, characterised in that front and rear edges of said pole plate are correspondingly stepped at positions which lie on an elongate axis which extends parallel to the axis of said linear array.

7. A linear motor according to claim 6 wherein said elongate axis on which said front and rear edges are stepped lies substantially midway between opposite elongate side edges of said pole plate.

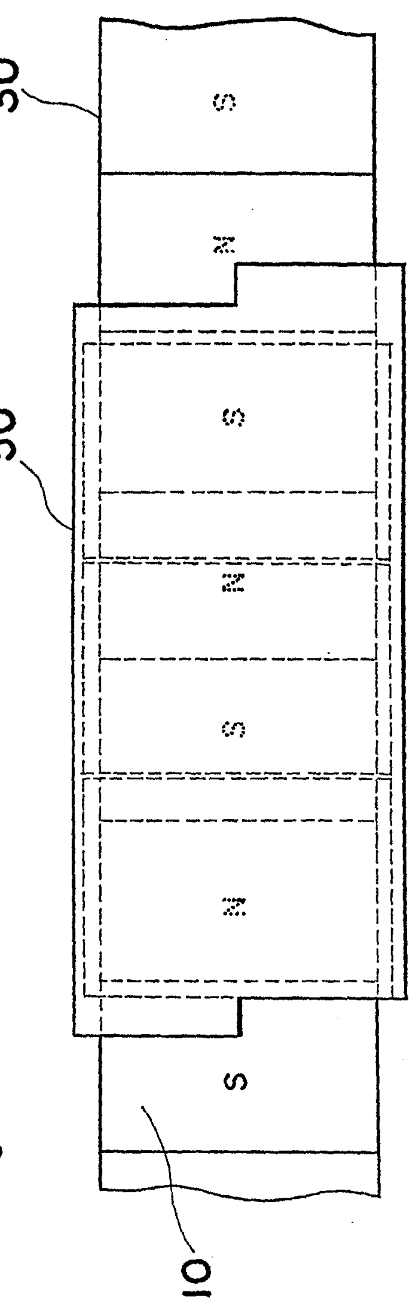

Fig. 1(A)

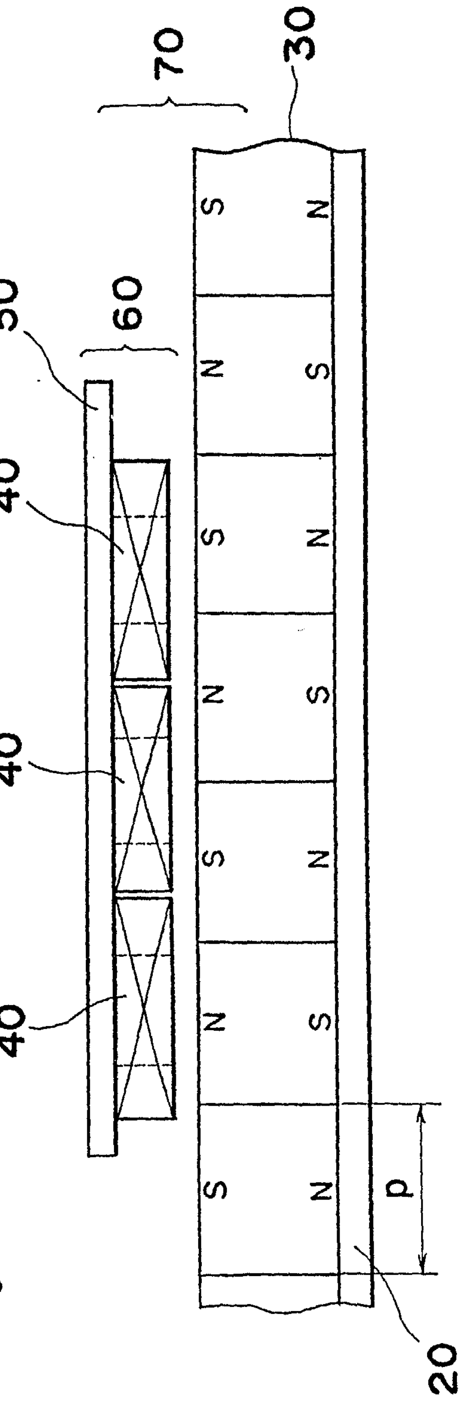

Fig. 1(B)

Fig. 2(A)

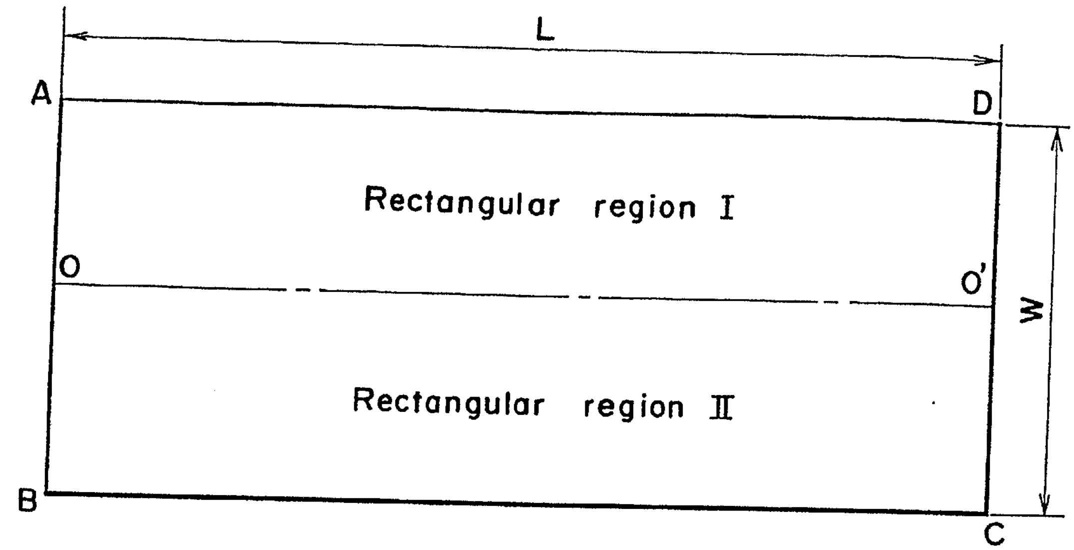
L
A
D
Rectangular region I
O
O'
W
Rectangular region II
B
C

Fig. 2(B)

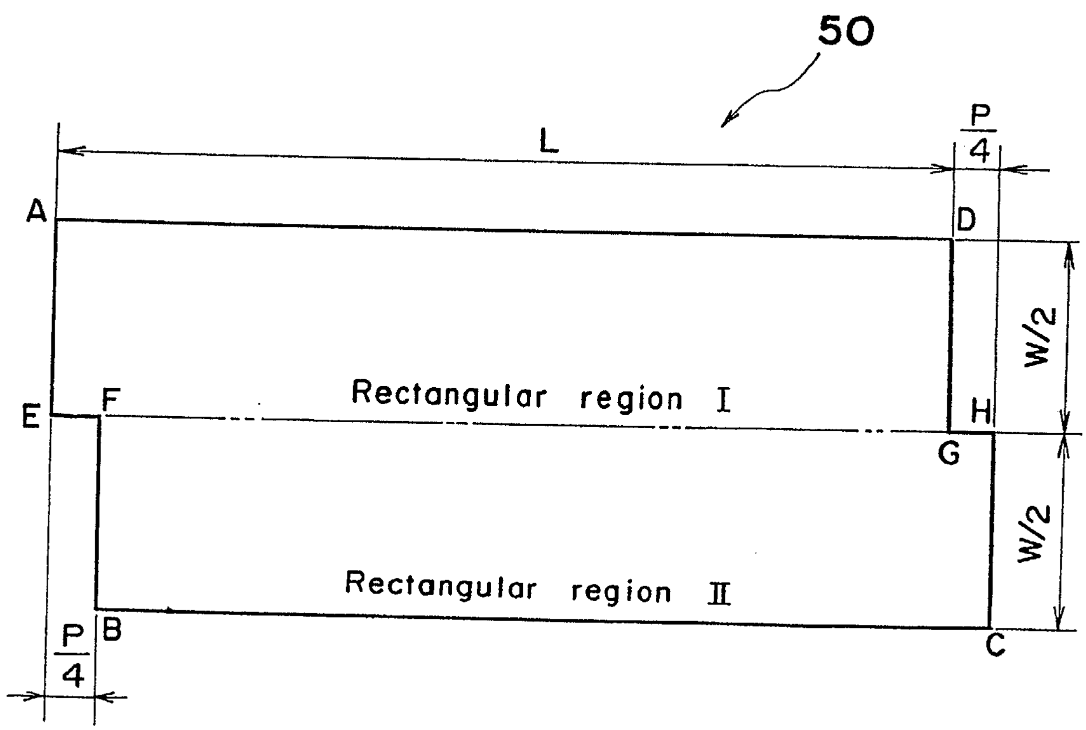
50
L
P/4
A
D
W/2
E
F
Rectangular region I
H
G
W/2
Rectangular region II
P/4
B
C

Fig. 3 (A)

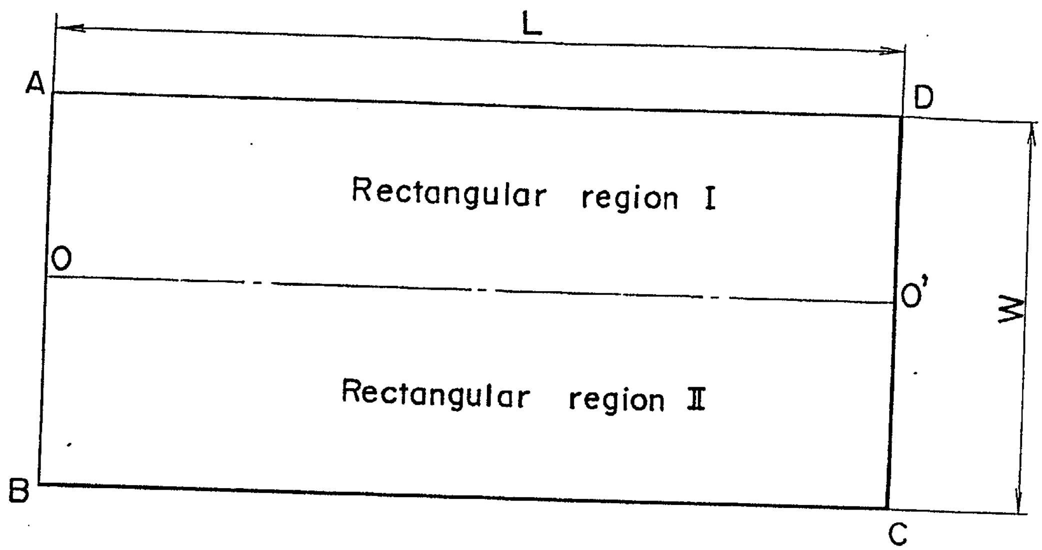
L
A
D
Rectangular region I
O
O'
W
Rectangular region II
B
C

Fig. 3 (B)

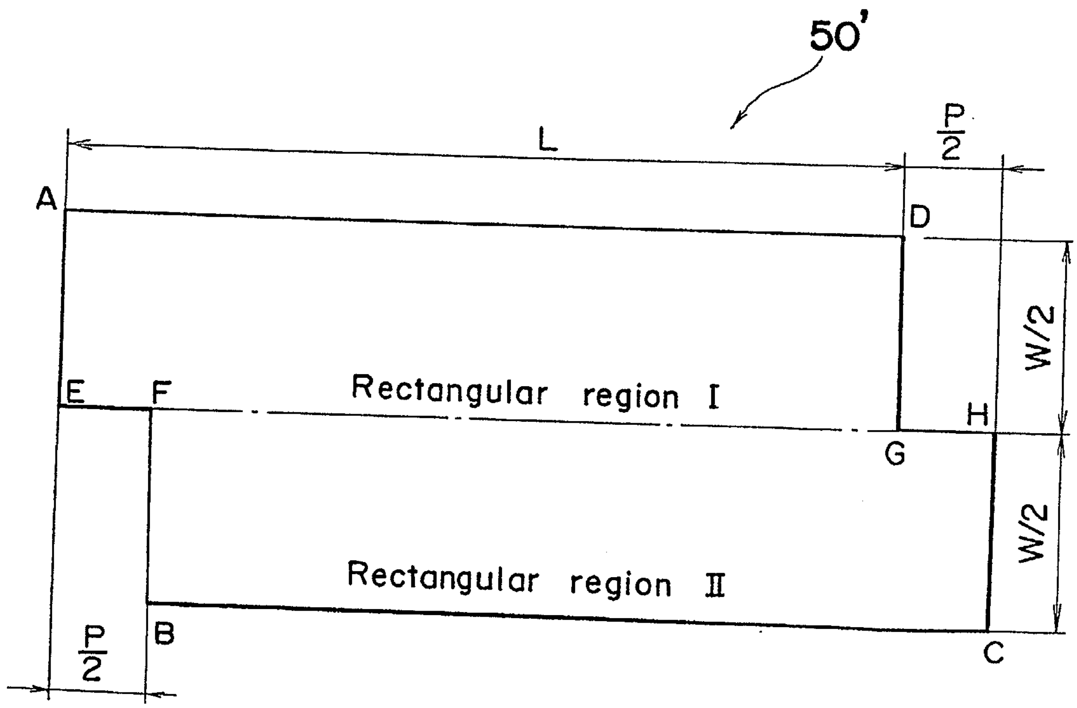
50'
L
P/2
A
D
W/2
E
F
Rectangular region I
H
G
W/2
Rectangular region II
B
C
P/2

Fig. 4(A)

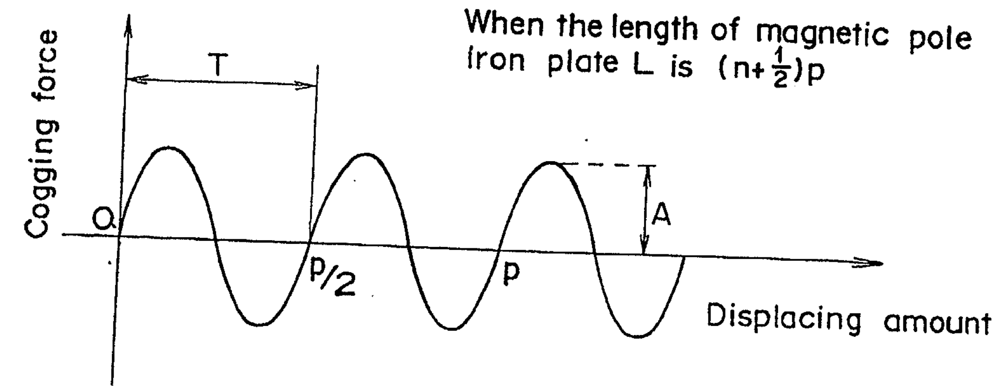

Fig. 4(B)

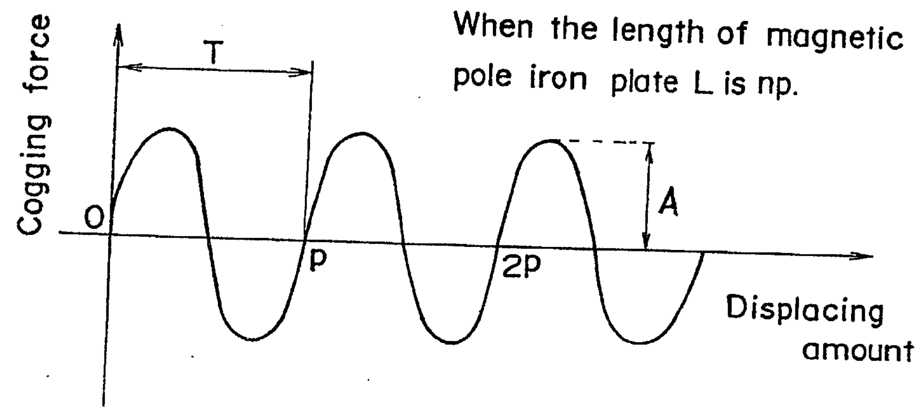

Fig. 4(C)

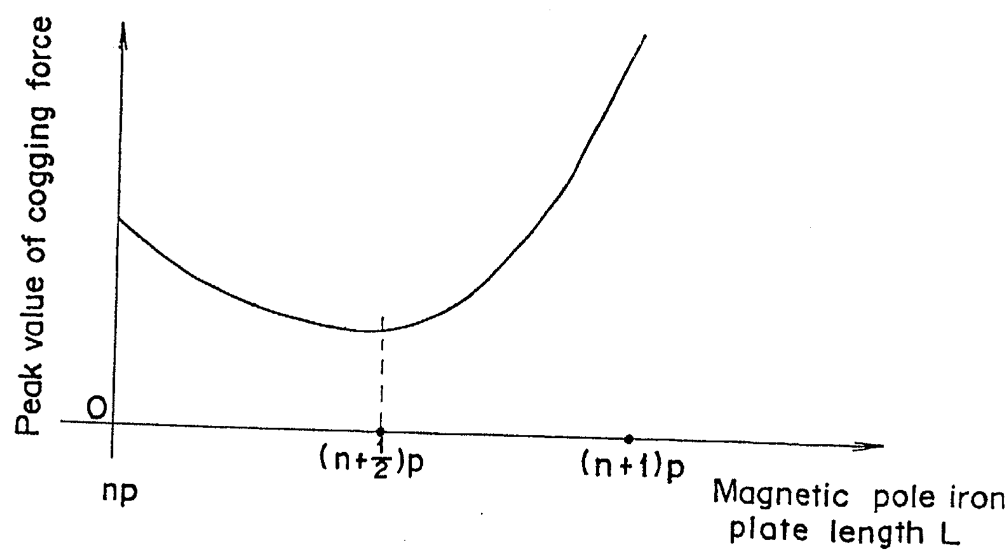

Fig. 5

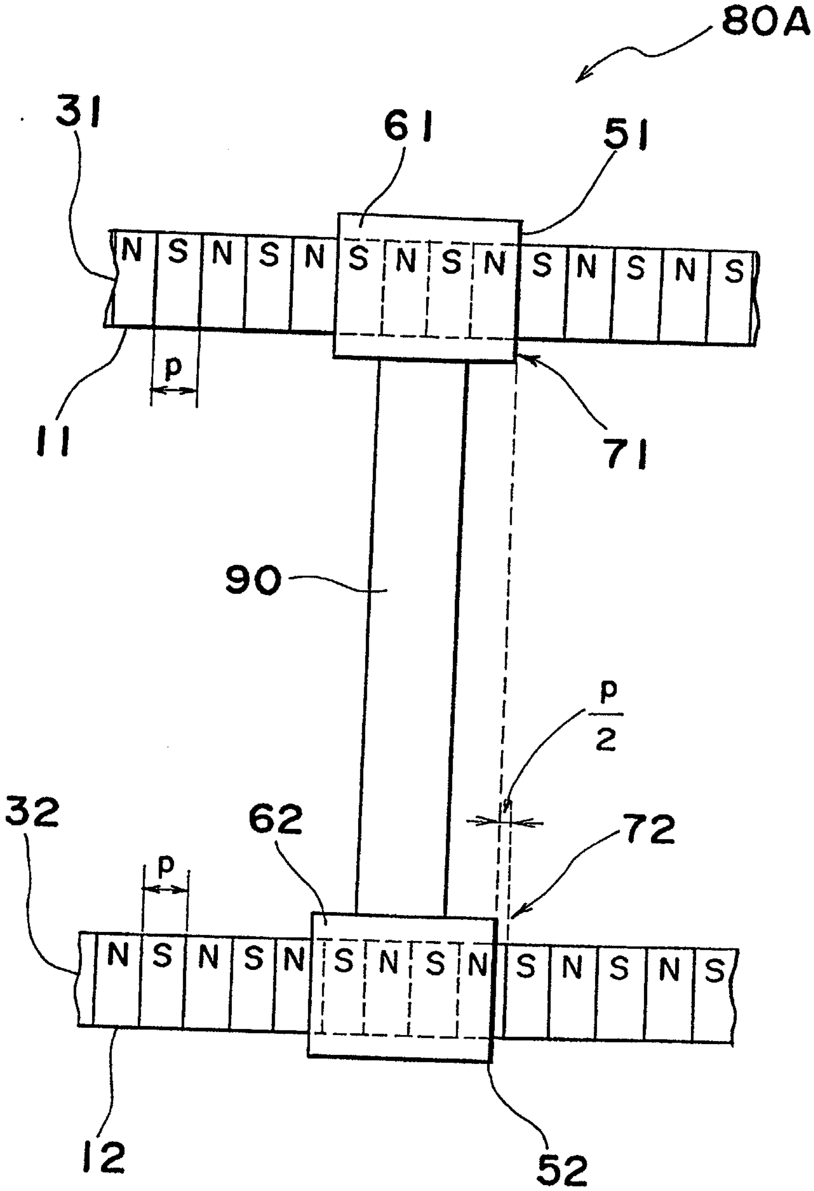
80A
31
61
51
N S N S N S N S N S N S N S
p
11
71
90
p/2
32
62
72
p
N S N S N S N S N S N S N S
12
52

Fig. 6

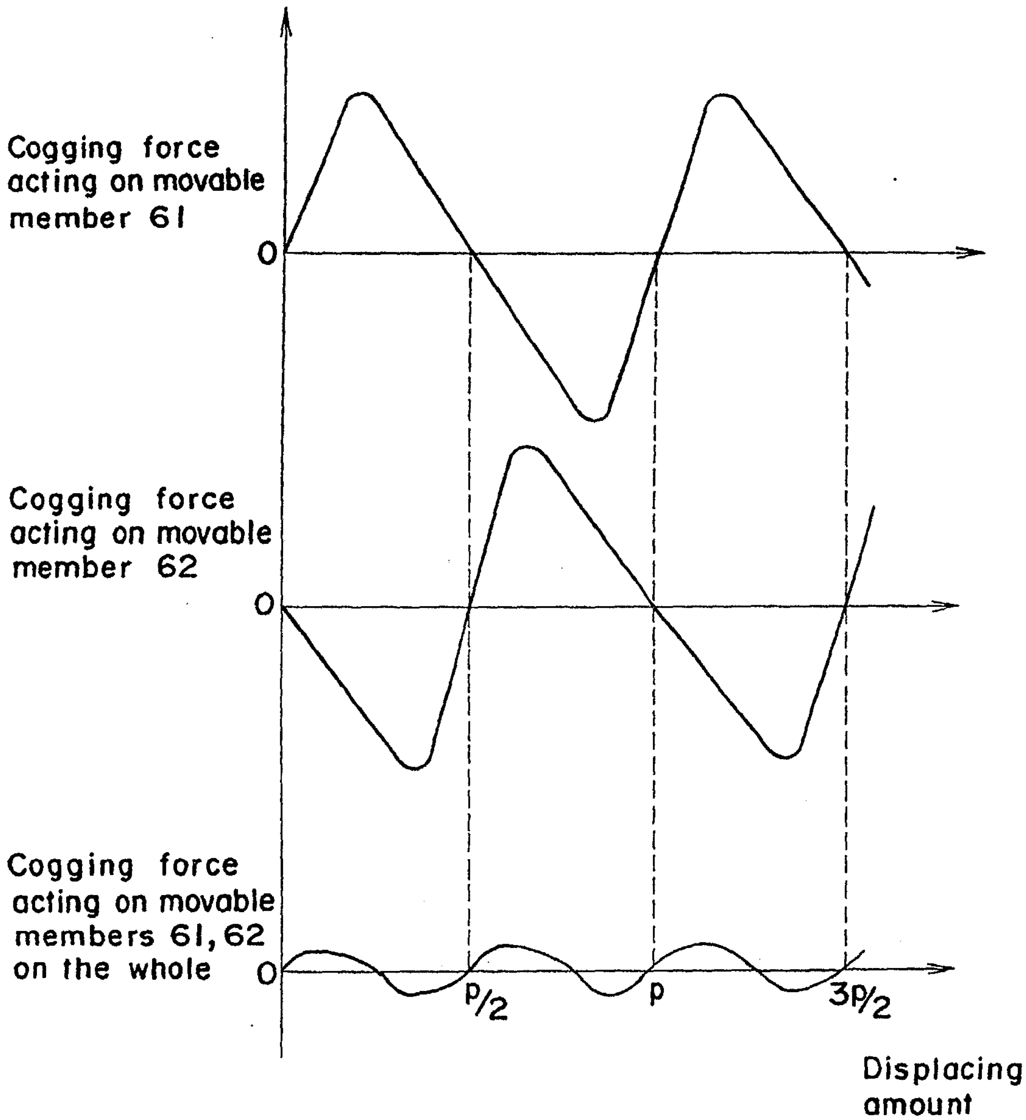
Cogging force
acting on movable
member 61
0
Cogging force
acting on movable
member 62
0
Cogging force
acting on movable
members 61, 62
on the whole
0
P/2
P
3P/2
Displacing
amount

Fig. 7

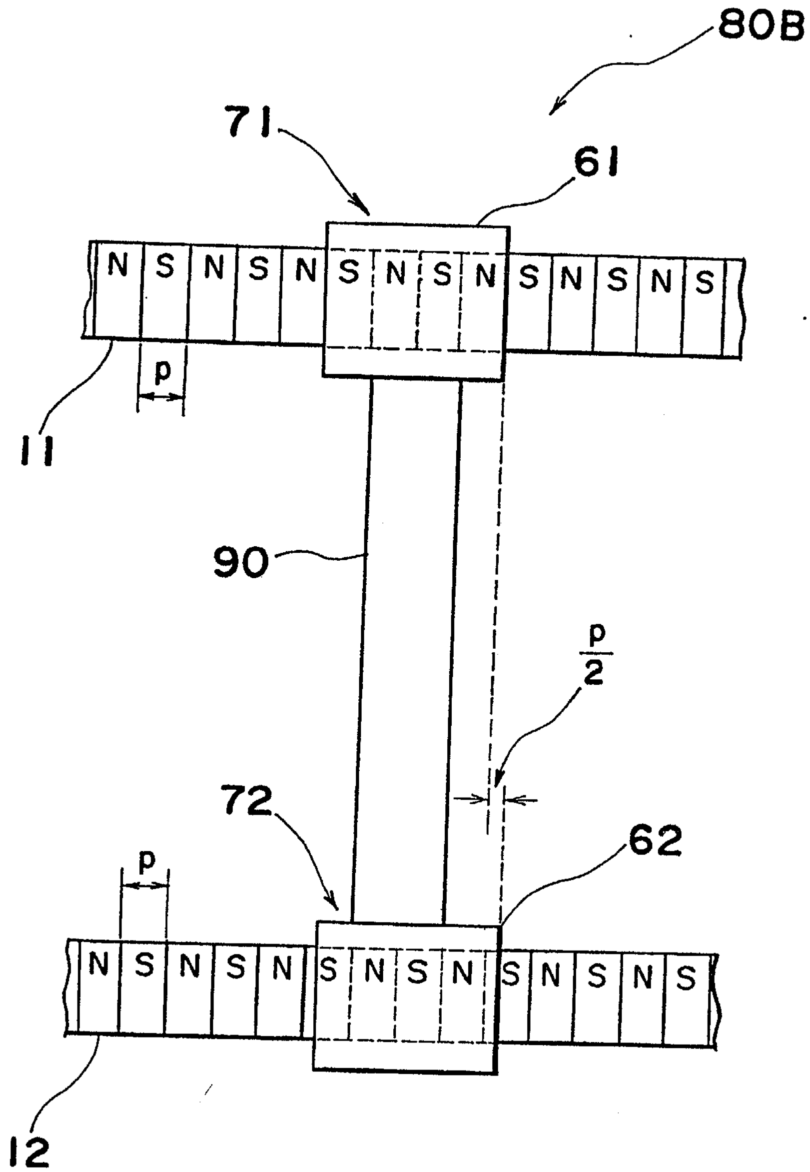

Fig. 8 PRIOR ART